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THE LATEST METHOD OF SEWAGE TREATMENT[1]

By Edward Bartow

Sewage treatment by aeration in the presence of sludge is the latest development in sewage disposal. Air has always played an important rôle in sewage disposal. The earliest application of air was the exposure of sewage on the ground or in shallow pools. The disposal of sewage by irrigation is, therefore, an aeration process. No more sewage can be added to land than can be thoroughly oxidized. The disposal of sewage by dilution in streams also depends on the amount of air present. The amount of sewage which can be purified by a stream is limited by the amount of dissolved oxygen present. The efficiency of the stream depends upon the amount of water or the amount of oxygen in solution or the possibility of reaeration.

Intermittent sand filtration where sewage is added intermittently to sand beds is an aeration process, for between the periods of flooding with sewage, air is allowed to enter the pores of the sand. The action of contact beds is of a similar nature. Coarser material is used and between the periods of flooding air enters the interstices and is the purifying agent. Sprinkling filters, the most practical process up to the time of the suggestion of activated sludge, depend upon aeration accomplished by spreading the sewage in a finely divided state into the air.

Preliminary to these aeration processes preparatory treatment is necessary. Preparatory treatment consists in using screens, grit chambers, settling tanks, digestion tanks or chemical precipitation. The preparatory treatment varies according to conditions. For example, three cities visited in Europe use different degrees of preparatory treatment prior to disposal by dilution. Munich uses no screening whatever, the water in the Yser being of sufficient quantity and sufficiently aerated to dispose of the sewage. Hamburg can dispose of its sewage in the lower Elbe using only coarse screening, but Dresden on the upper Elbe must pass its sewage through fine screens before emptying it into the river.

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[1] A paper read at meeting of Iowa Section American Water Works Association, December 3, 1915.

Grit chambers and settling tanks remove suspended matter. The amount of purification is comparable with the amount of purification by screening.

Digestion tanks accomplish the partial destruction of the suspended solids and soluble organic matter by anaerobic bacteria.

The addition of chemicals assists sedimentation and retards digestion, giving an increased amount of sludge, but a much improved effluent. Neither the screening nor the sedimentation nor the digestion nor the chemical precipitation produce complete purification. Aeration processes must complete the purification.

The latest process, the aeration of sewage in the presence of sludge, has had a gradual development. Numerous experiments of blowing air into sewage have been made both in America and in Europe. Until recently none of the experiments were at all promising and the conclusion was that such means of purification was not practical. In this country, the first promising method was that used by Black and Phelps[2] in New York. They blew air through the sewage as it passed over a series of inclined wooden gratings. This sewage was in contact with the air for varying periods up to twenty-four hours. The results were promising enough to cause Black and Phelps to recommend the construction of a larger plant for Greater New York. That plant has not been constructed and the experimental tank has been adapted to experiments with activated sludge.

The next experiments are those reported by Clark, Gage and Adams[3] at the Massachusetts State Board of Health Experiment Station in Lawrence. Air blown through sewage reduced the organic constituents. The seeding of the sewage with green growths accelerated the action. Their best results were obtained when the tank contained slabs of slate covered with a brown growth of sewage matters. This treatment produced an effluent which could be filtered at several times the normal rate. It, however, simply prepared the sewage for addition to sand beds, and was not considered a final process.

Gilbert J. Fowler of the University of Manchester was in this country in November, 1912, in connection with the disposal of the sewage of Greater New York and visited the Massachusetts Experiment Station. Fowler and Mumford carried on experiments with a specific bacillus which they named M-7 which was collected from the waste water from a colliery. This bacillus with aeration has the power of separating iron as ferric hydroxide from iron bearing sewages, carrying down with it the suspended matter, and furnishing a nonputrescible effluent. Fowler suggested to Ardern and Lockett, who were in charge of the Manchester Sewage Disposal Works, that they try experiments in aerating sewage on lines somewhat similar to what he saw in Massachusetts. As a result the activated sludge process is being developed.

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[2] Report Concerning Location of Sewer Outlets and the Discharge of Sewage into New York Harbor (1911), 64–78.

[3] Annual Report Massachusetts State Board of Health (1913), 45, 288–304.

The first description of it was given by Ardern and Lockett,[4] April 3, 1914, at a meeting of the Manchester Section of the Society of Chemical Industry. In their first experiments Ardern and Lockett used bottles having a capacity of 5 pints, and drew the air through the sewage by means of an ordinary filter pump. Air was drawn through the sewage until it was completely nitrified, requiring about five weeks. The supernatant liquid was drawn off and additional sewage added. This method of treatment was repeated a number of times with the retention each time of the deposited solids. As the amount of deposited matter increased the time required for each succeeding oxidation gradually diminished. Finally a well oxidized effluent, equal to that from efficient bacterial filters, was obtained in from 6 to 9 hours.

In their second series of experiments, reported to the Manchester Section of the Society of Chemical Industry,[5] November 6, 1914, they used barrels of 50 gallons capacity and added the air through porous tile. They have tried treatment with a continuous flow of sewage without conclusive results. In later experiments they used tanks of 20,000 gallons capacity. Their results were very satisfactory and led to additional work in England, especially at Salford where Duckworth[6] and Melling[7] adapted scrubbing filters to the use of the activated sludge process with great success. In August, 1914, the author had the privilege of meeting Professor Fowler and of seeing the work which had been done under his direction. On returning to this country, consulting with Fowler, experiments[8] were begun with F. W. Mohlman at the University of Illinois on November 2, 1914, using bottles of 3 gallons capacity. On January 4, 1915, a tank 9 inches square and 4½ feet deep was put in operation. In the bottom of this tank was placed a porous plate made of material known as "Filtros," furnished by the General Filtration Company, Rochester, New York. The plates are made of a very pure and carefully graded quartz, fused together with powdered glass.

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[4] *J. Soc. Chem. Ind.*, 33, 523–539.

[5] *J. Soc. Chem. Ind.*, 33, 1122–1124 (1914).

[6] *Surveyor*, 46, 681–682 (1914).

[7] *J. Soc. Chem. Ind.*, 33, 1124–1130.

[8] *Jour. Ind. Eng. Chem.*, 7, 318 (1915). *Eng. News*, 73, 647–648 (1915); *Eng. Record*, 71, 421–422 (1915); *Eng. Contrg.*, 43, 310–311 (1915).

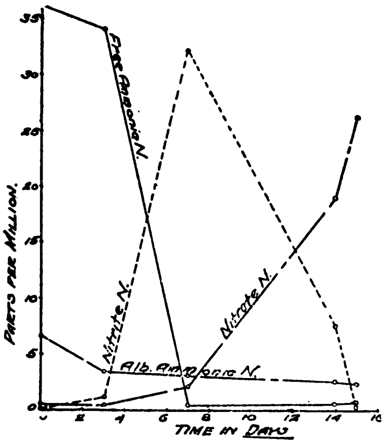

FIG. 1. NITRIFICATION OF SEWAGE. NO ACTIVATED SLUDGE PRESENT UNIFORM DISTRIBUTION OF AIR THROUGH POROUS PLATE

The results of our first experiments were similar to those of Ardern and Lockett. Sewage placed in the bottles or in the little tank was submitted to a current of air for a sufficient period to oxidize it completely. The oxidization is best measured by the content of ammonia, nitrate, and nitrite nitrogen. Oxidation has been carried to completion five different times with practically the same results. The time required for oxidation differed, but the courses of the reaction were similar. As an example in one of these experiments, at the beginning, 35 parts per million of ammonia nitrogen were present (see fig. 1). The ammonia nitrogen remained practically constant for about 4 days and then quite rapidly decreased so that at the end of about 7 days it was gone. There were no nitrates nor nitrites present in the raw sewage. The nitrites increased as the ammonia decreased. Then for a few days the nitrites remained constant and then decreased, the nitrates which were zero at the start increasing as the nitrites decreased. At the end of fifteen days, nitrification was complete, the nitrite nitrogen had practically disappeared and the nitrate nitrogen had increased to about 25 parts per million. When the oxidation was complete the supernatant liquid was replaced by fresh sewage, the sludge being left. This process was repeated. With each change less time was required for oxidation, as for example, 15 days for the first, 4 days for the second, and 2 days for the third, and so on, until with the thirty-first treatment oxidation was complete in 5 hours.

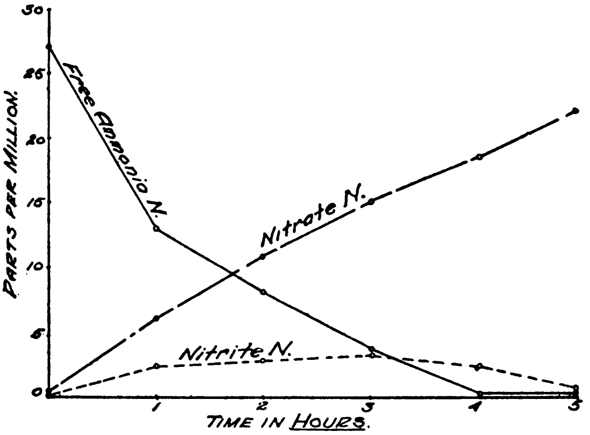

FIG. 2. NITRIFICATION OF SEWAGE. ACTIVATED SLUDGE PRESENT 1 SLUDGE: 5 SEWAGE

With accumulation of sludge as the process is repeated the reaction follows a different course, for example (see fig. 2), using a sewage with 27 parts per million of ammonia nitrogen, the ammonia decreased and is practically eliminated in 5 hours. The nitrite nitrogen never increased to any extent, the nitrate nitrogen begins to increase almost at the start, increasing as the ammonia nitrogen decreases, and reaches its maximum when the ammonia nitrogen has disappeared. It is not necessary to obtain complete nitrification to obtain a clear or stable effluent. More information must be obtained before the amount of nitrification required can be known.

The process is undoubtedly bacteriological. The sludge is very rich in bacteria but the number in the effluent is comparatively small.

The fresh sludge is odorless. It will putrefy if left with a large amount of water. After filter pressing it is stable. The dried sludge has an odor similar to that of fertilizers.

As in other sewage disposal processes, the ultimate disposal of the sludge is of great importance. Near the seaboard it is possible to carry it out to sea, but in the interior, the problem of sludge disposal is often very serious.

In the experimental plant at the University of Illinois in Urbana, they have tried to study all phases of the process,[9] and have paid especial attention to the sludge.

The amounts of sludge formed and its chemical composition evidently vary with the concentration of the sewage, and with temperature conditions. The sewage treated in the experimental plant during rainy weather contains large amounts of diluting water, which reduces the amount of sludge per unit of water. The diluting water carries considerable dirt from the streets which reduces the nitrogen content of the sludge obtained. Also during warm weather, bacteriological action is more rapid, and apparently, the amount of sludge is considerably reduced.

The sludge obtained in the process is flocculent, resembling a freshly formed precipitate of ferrous-ferric hydroxide. It separates easily from the clarified water, and after one hour's settling contains about 98 per cent of water. On further standing, about one-half of this water can be removed. The remaining material can be dried by filter pressing or by drying on beds of sand and evaporating over steam baths.

The disposal of the sludge can be most easily accomplished if it has manurial value. That activated sludge has manurial value is shown by its chemical composition, by its reaction with various soils, and by its effect on the growth of plants. Specimens of sludge obtained at the experimental plant have varied in nitrogen content from 3.5 to 6.4 per cent. The lower values were obtained during periods of high water. The tests of the fertilizer value have been made on the richer specimens which were first obtained.

Through the courtesy of Mr. Paul Rudnick, chief chemist, Armour and Company, Chicago, the availability, according to alkaline permanganate method as used by the New England states was shown to be below 50 per cent (44.7 per cent), and the sludge would be classed as an inferior ammoniate, but the availability according to the neutral permanganate method which has been adopted by the southeastern states was shown to be about 85 per cent (89.0 per cent), and would therefore be classed as satisfactory.

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[9] *J. Ind. and Eng. Chem.*, 7, 318–320.

Tests have been made by Prof. C. B. Lipman, according to a method described by Lipman and Burgess,[10] in which a fertilizer and a soil are incubated for a month. The amount of nitrogen changed into nitrate is then determined. This amount is an index of the availability of the nitrogen with respect to the soil used. The results obtained were reported by Professor Lipman as follows:

The activated sludge used contained 6.2 per cent total nitrogen and no nitrate. The hundred grams of soil in every case contained nitrate as follows:

	milligrams nitrogen
Anaheim soil	1.0
Davis soil	0.3
Oakley soil	0.1

The amounts of nitrate produced in one month's incubation from the soil's own nitrogen and from the nitrogen of the sludge mixed with the soil in the ratio of one part of sludge per hundred of soil as is follows:

	milligrams nitrate produced
Anaheim, without sludge	6.0
Anaheim, with sludge	10.0
Davis soil, without sludge	4.2
Davis soil, with sludge	14.0
Oakley soil, without sludge	2.2
Oakley soil, with sludge	4.0

The Davis soil is the best nitrifying soil of the three, especially for high grade organic material. Anaheim is next, and the Oakley by far the poorest. Indeed, the last named does not nitrify in a period of a month in the incubator the nitrogen of dried blood at all.

These figures indicate that the general tendency is to make available the nitrogen of sludge in type soils at about the same rate that nitrogen is transformed into nitrate in such organic nitrogenous fertilizers as fish guano. While it seems to hold a medium position, it nevertheless resembles very much more closely in its general chracteristics, so far as available nitrogen is concerned, the so called high grade organic nitrogenous fertilizers, dried blood and high grade tankage, etc., rather than the low grade nitrogenous fertilizers, steamed bone meal, cotton seed meal, garbage tankage, etc.

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[10] Univ. of Calif., Bul. 351 (1915).

Although the chemical tests and the nitrification tests with soils indicate that the activated sludge has a high fertilizer value, the final test must be its effect on plant growth. Pot cultures, using wheat, were started in March, 1915, by W. D. Hatfield[11] under the general direction of Prof. C. G. Hopkins and with the assistance of Mr. J. C. Anderson. The contents of the pots in which the wheat was planted were as follows:

POT NUMBER	1	2	3	4
	grams	*grams*	*grams*	*grams*
(1) White sand	19,820	19,820	19,820	19,820
(2) Dolomite	60	60	60	60
(3) Bone meal	6	6	6	6
(4) Potassium sulphate	3	3	3	3
(5) Activated sludge	0	0	20	0
(6) Extracted sludge	0	0	0	20
(7) Dried blood	0	8.61	0	0

Each pot contained an equivalent of 5 tons per acre of dolomite, ½ ton per acre of bone meal, and 500 pounds per acre of potassium sulphate.

Pot 1, the check pot, contained only 60 milligrams of nitrogen which were added in the bone meal. This small amount was without significance since the same amount was added to the other pots. Pot 2 contained an equivalent of 120 pounds of nitrogen per acre added in the form of dried blood. Pots 3 and 4 contained an equivalent of 120 pounds of nitrogen in the form of dried activated sludge, one ton of sludge per acre. Following is an analysis of the sludge used:

	per cent
Total nitrogen	6.3
Phosphorus (P_2O5)	2.69
Ether soluble (3 hours extraction)	4.00
Ether soluble (16 hours extraction)	11.8

Thirty wheat seeds were planted, two seeds in each of fifteen holes, in each pot. At the end of eighteen days the plants were thinned to fifteen of the best in each pot in most cases leaving one plant to each hole. In twenty days from date of planting there was a marked showing in favor of the plants in pots 3 and 4. In twenty-three days the plants in pots 3 and 4 (see fig. 3), were growing far

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[11] *Ind. Eng. Chem.*, 7, 318–320.

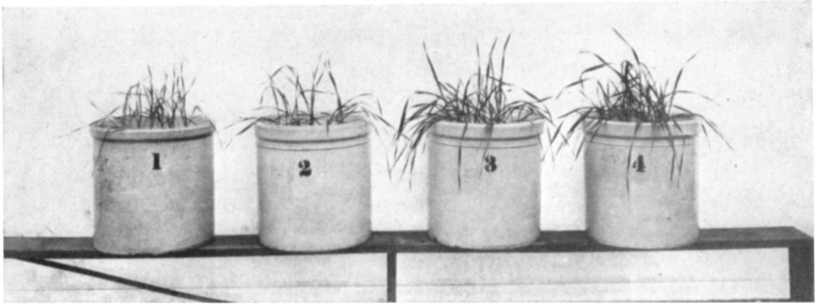

FIG. 3. POT CULTURES, WHEAT TWENTY-THREE DAYS AFTER PLANTING

Each pot contains pure white sand to which the same amount of plant foods except nitrogen have been added. No. 3 contains 20 grams dried activated sludge. No. 4 contains the same amount extracted with ligroin. No. 2 contains an equivalent of nitrogen from dried blood and No. 1 contains no nitrogen.

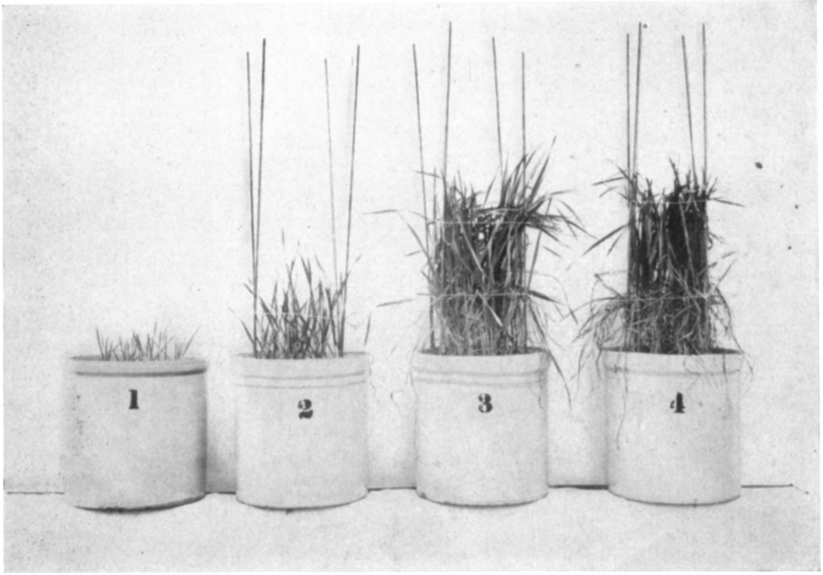

FIG. 4. POT CULTURES, WHEAT SIXTY-THREE DAYS AFTER PLANTING

Each pot contains pure white sand to which the same amount of plant food except nitrogen have been added. No. 3 contains 20 grams dried activated sludge. No. 4 contains the same amount extracted with ligroin. No. 2 contains an equivalent of nitrogen from dried blood and No. 1 contains no nitrogen.

ahead of 1 and 2. After nine weeks the difference was very marked (see fig. 4).

In fourteen weeks the plants in pots 3 and 4 began to head and in fifteen weeks there were about twenty good heads in each. The plants in pot 1 were very weak, while those in pot 2 were just beginning to develop heads.

When it was first noticed that the plants fertilized with sludge were growing much better than those fertilized with dried blood, in order to confirm the results a second series of pot cultures was started. In this series the sludge was compared with dried blood, nitrate of soda, ammonium sulphate and gluten meal. This series contained fourteen pots, two check pots, six containing nitrogen equivalent equal to an application of 20 grams of sludge, and six containing nitrogen equivalent to 30 grams of sludge. The plants in this series grew faster than those in the first because of better weather. They showed exactly the same characteristics that the plants in the other series showed. The plants fertilized with sludge were the best. The results confirmed the results obtained in the first series. At the end of five weeks striking differences were noticeable (see fig. 5). The pots containing the equivalent of 30 grams of sludge gave no better results than those with an equivalent of 20 grams.

When the wheat matured it was carefully harvested and calculations made to determine the yield per acre. The results are shown in a table.

Amounts of wheat and straw obtained in the first series

POT NUMBER	1	2	3	4
Number of heads	14.0	15.0	22.0	23.0
Number of seeds	85.0	189.0	491.0	518.0
Weight of seeds	2.38 g.	5.29 g.	13.748 g.	14.504 g.
Bushels per acre (calculated)	6.20	13.6	35.9	37.7
Average length of stalk	19.40 in.	23.0 in.	35.40 in.	36.1 in.
Weight of straw	2.25 g.	8.25 g.	26.75 g.	26.21 g.
Tons per acre (calculated)	0.18	0.68	2.23	2.18

The control series gave results corresponding to those of the first series.

The surprisingly rapid growth of the wheat fertilized by the sludge must be due for the most part to nitrogen present in a very available form. It may be due in part to the phosphorus (2.69 per cent) which is present in the sludge. At the time of making the pot cultures the phosphorus was not considered since it was present in such a small quantity. The growth may be due in part to the organic matter present in the sludge, since the sand used contains no organic matter.

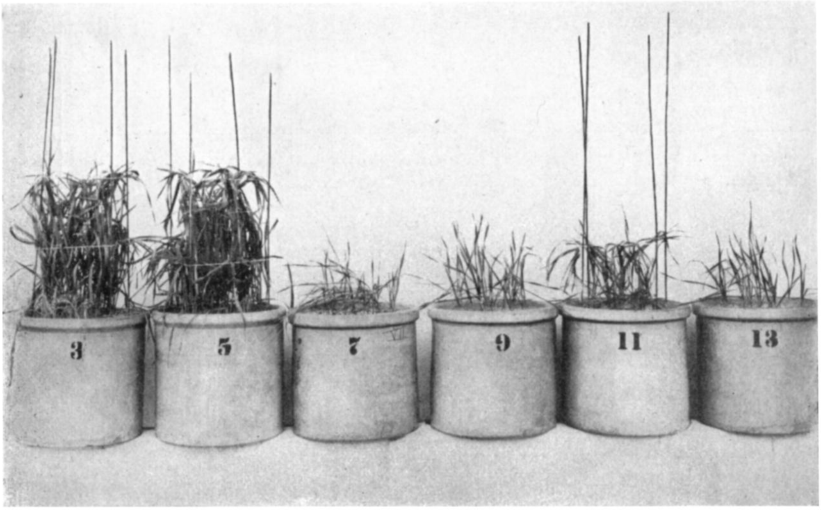

FIG. 5. POT CULTURES, WHEAT SERIES 2, THIRTY-FIVE DAYS AFTER PLANTING

Each pot contains pure white sand to which the same amount of plant foods except nitrogen have been added. No. 3 contains 20 grams dried activated sludge. No. 5 contains 20 grams of dried activated sludge from which other soluble matter has been removed. No. 7 contains the nitrogen equivalent from sodium nitrate. No. 9 contains the nitrogen equivalent from ammonium sulphate. No. 11 contains the nitrogen equivalent from gluten meal. No. 13 contains the nitrogen equivalent from dried blood.

The sludge causes such a rapid growth of wheat, that it should be valuable to truck gardeners, to rush the spring crops. To test its value to the market gardener, three plots each 2 feet by 3 feet were laid out in a field. One plot was not fertilized, one was fertilized with an equivalent of 126 pounds of nitrogen, 1 ton of sludge per acre, and the third with an equivalent of extracted sludge. On April 24, 1915, two rows of radishes and lettuce were planted in each of the three plots. The plants in the plot where the extracted sludge was used, came up first, a little ahead of those in the plot where the unextracted sludge was used. At the end of four weeks the plants were thinned. The roots of the radishes from the treated plots were already red and quite rounded near the tops while those from the untreated plots had not yet started to swell and had not become red.

On June 1, 38 days after planting, the six best plants of lettuce and radishes were taken from each plot (see fig. 4). The differences in size were very marked.

Comparison of the lettuce and radishes from unfertilized and fertilized plots

PLOT	TREATMENT	WEIGHT OF LETTUCE	WEIGHT OF RADISHES
		grams	*grams*
1	None	4.5	23.4
2	Sludge	6.3	63.0
3	Extracted sludge	6.8	68.0

The increase in weight, due to the sludge, is 40 per cent in the lettuce, and nearly 300 per cent in the radishes. The radishes from the sludge pots when cut open and eaten were found to be very crisp and solid, and to have a good flavor.

These pot cultures and gardening experiments show that the nitrogen in "activated sludge" is in a very available form and that activated sludge is valuable as a fertilizer.

The process is attracting a great deal of attention in America, and a very good statement concerning the work being done is given in *Engineering News*, July 15.[12] Mr. M. N. Baker has given an editorial review of the subject. The most extensive work is being done at Milwaukee. An article by Mr. T. Chalkley Hatton[13] gives a more complete account of the Milwaukee experiments. Two tanks of 1 x 5 x 10 feet deep and one tank 10½ x 32 x 10 feet deep have been operated on the fill and draw plan and one tank 10½ x 32 x 10 feet deep has been operated on the continuous plan. The Milwaukee Sewerage Commission has awarded contracts for the construction of a plant to treat 2,000,000 gallons of sewage per day by continuous flow. At Baltimore, they have been working on a small scale but have also adapted two of the new Imhoff tanks for use by this process, and it is expected that in a short time they will be treating sewage with activated sludge on a large scale. At Washington, the Hygienic Laboratory of the Public Health Service is experimenting on a small scale and is coöperating with the Department at Baltimore in their experiments. At Cleveland, experiments are being carried on in the sewage experiment station. They have adapted tanks 5 x 10 and 5 feet deep which they used in their sewage experiments to the process, and while it has barely begun they are getting promising results. Experiments are to be carried out on a larger scale. At Regina, Saskatchewan, experiments on a considerable scale have been carried out and their

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[12] *Eng. News*, 74, 164–171 (1915).

[13] *Eng. News*, 74, 134–137 (1915).

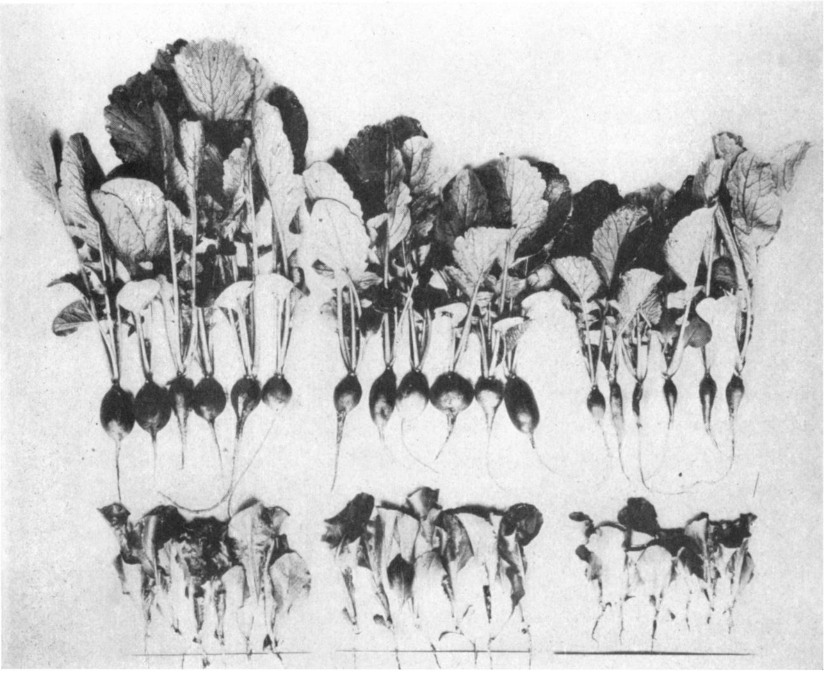

FIG. 6. GARDENING EXPERIMENTS THIRTY-EIGHT DAYS AFTER PLANTING

Radishes. From left to right, six radishes fertilized with extracted sludge, six radishes fertilized with sludge, six radishes unfertilized. Lettuce. Six heads fertilized with extracted sludge, six heads fertilized with sludge, six heads unfertilized.

results are reported by R. O. Wynne-Roberts.[14] At Houston, Texas, they are planning to use the process in a plant to ultimately treat the sewage from 160,000 people. They do not expect to obtain complete nitrification as they do not believe that a completely purified effluent is necessary. In Chicago the Sanitary District of Chicago is using tanks about two feet in diameter and eight or ten feet high with quite satisfactory results, using the waste from the stock yards, one of the most difficult wastes to treat. A larger plant is being built. At the University of Illinois four reinforced concrete tanks have been completed and put in operation. These tanks, operating on the fill and draw system, are designed for studying in a comparative manner the amount of air required, the best method for distributing the air, the time required for purification, and the quantity and quality of activated sludge formed.

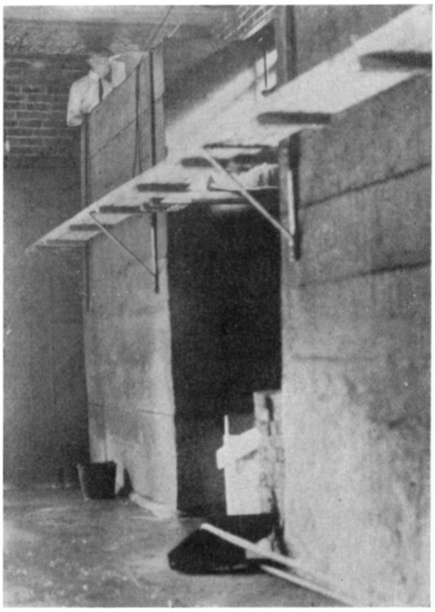

FIG. 7. TANKS FOR PURIFICATION OF SEWAGE BY AERATION IN PRESENCE OF ACTIVATED SLUDGE

The tanks are located in the basement of the University power plant (see fig. 7). The room is not affected by heat from the boilers and conditions are similar to those which would be obtained by housing a plant.

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[14] *Canadian Engineer*, 29, 112, 113 (1915).

It was very easy to tap the city of Champaign main sewer which passes underneath the coal hopper (see fig. 8) of the power plant. The sewage is pumped to the tanks by a 2 h.p. centrifugal pump run by a direct connected motor.

Each tank is 3 feet 2 inches square having an area of 10 square feet. Each tank is 8 feet 5 inches in depth above 1½ inch Filtros plates which are used for diffusing the air. In two tanks there are 9 plates, each 12 inches square, covering the entire floor. In the third tank there are 3 plates, covering one-third the area of the floor, forming the bottom of a central trough. The remainder of the bottom slopes to the plates at an angle of 45 degrees. In the fourth tank is a single plate in the center covering one-ninth the area with the bottom sloping to it at an angle of 45 degrees from all sides. Below the plates is an air space 4 inches deep. A pet cock is provided to relieve the air pressure when draining the tank and to prevent air bubbles from rising and stirring up the sludge. The air obtained from the University compressed air plant at a pressure of 80 pounds is reduced by a pressure reducing valve to 8 pounds and is further regulated by a hand operated valve before passing through meters on each tank. The pressure under which it enters the tank is sufficient only to overcome the pressure of the sewage and friction of the plates equivalent to about 8 inches of mercury or a little less than 4 pounds per square inch.

Two outlets for the effluent are respectively 2 feet 6 inches and 5 feet 7 inches above the porous plates. A tank can be filled in 6 minutes and drained to the lower outlet in eight minutes.

Experience has shown that a lower outlet connected to a floating outlet would be preferable. A fixed outlet is objectionable because sludge is at times drawn out with the effluent. In order to prevent this loss, a floating outlet made of two-inch pipe connected together with loose joints, has been placed in tank C. With this arrangement no sludge has been lost and accurate data are expected concerning the amount of sludge formed from the sewage.

The amount of sludge must be determined by weight on the dry basis for it has been noted that its volume and rate of settling vary with the amount of air applied. If an unusually large amount of air has been applied, the sludge will settle more slowly and will occupy a much greater volume, even after prolonged settlement, than it does when less air has been applied.

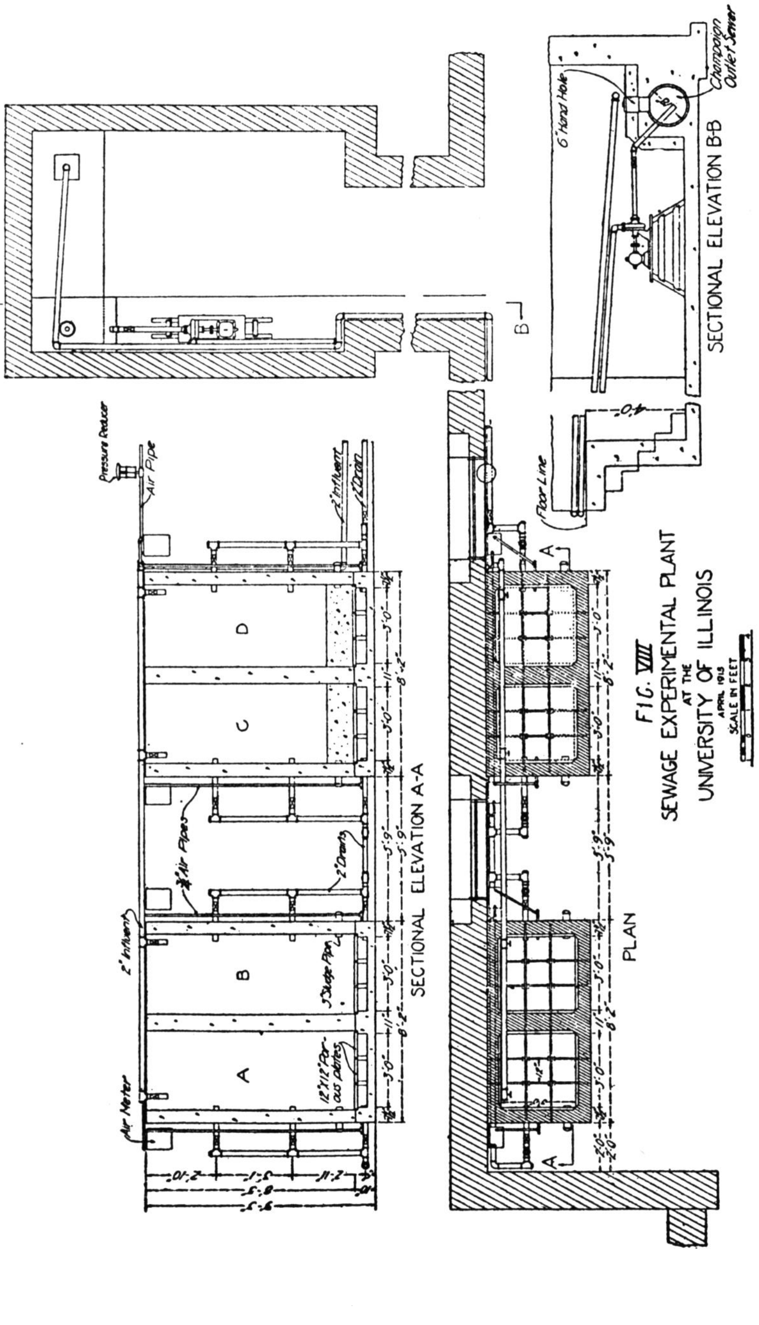

FIG. VIII
SEWAGE EXPERIMENTAL PLANT
AT THE
UNIVERSITY OF ILLINOIS
APRIL 1915

BUILDING UP OF SLUDGE

If in accordance with previous practice, activated sludge is built up by complete nitrification of each portion of sewage added, it would require several weeks to put a plant in operation. In order to obtain sludge more quickly the English investigators have used sludge from sprinkling filters. At Milwaukee, Imhoff tank sludge has been aerated until it is aerobic and similar to activated sludge. Such a source of sludge would not be available in many places, especially at newly installed plants. The university plant has attempted to shorten the period of sludge formation.

Tanks A and B were filled with the same kind of sewage on May 5, 1915. The sewage in tank A was aerated continuously. The sewage in tank B was aerated 23 hours, allowed to settle, the supernatant liquid withdrawn and the tank was refilled with fresh sewage. This cycle was repeated daily. Determinations of the amount of sludge and of the degree of purification were made daily.

At the end of 10 days, after one hour's settling in Imhoff cones, 1.0 per cent of the volume in tank A consisted of sludge while about 10 per cent of the volume in tank B was sludge. The effluents from tank A which had been aerated 10 days and from tank B which had been aerated one day were equally stable while that from tank B was clearer.

Later experiments showed that satisfactory activated sludge could be built upon a 6 hour cycle. A considerable degree of purification is obtained from the beginning of the operation, and the time for building up adequate sludge for the process is cut down very decidedly.

DIFFUSION AREA REQUIRED

The bottom of tank C contains three square feet of Filtros plates as described above. The bottom of tank D contains one square foot. These tanks were put in operation July 6 and the sewage changed every 6 hours. There was a noticeable difference in the action in these tanks. Tank C gave some stable effluents after 5 days; tank D did not give stable effluents in 18 days. The sludge from C was of good appearance, while that from D was not as flocculent and at times had a septic odor. During the comparative experiment an average of 450 cubic feet of air per 400 gallons of sewage was used with tank C, and 360 cubic feet per 400 gallons of sewage with tank D. The amount of air given tank D was always sufficient to keep the sludge mixed with the sewage. In fact, the sewage in tank D was agitated much more violently than that in tank C. It was concluded that 1 square foot of filtros plate per 10 square feet of floor area is hardly sufficient. Of the four tanks tank C with 3 square feet of filtros plate per 10 square feet of floor area, has given the best results.

It was noted that it is quite essential that the plates be as nearly as possible at the same level. A variation of $\frac{1}{4}$ inch in level will cause uneven air distribution. The distribution seems to become more uniform the longer the plates are used.

QUALITY OF EFFLUENTS

The quality of the effluents has usually depended more on the strength of the raw sewage than upon any other variable. The tanks, when operating on a 6 hour cycle, were filled at 9 a.m., 3 p.m., 9 p.m., and 3 a.m. The strength of the raw sewage, estimated by the ammonia nitrogen, is for the 9 a.m. sewage between 20 and 35 parts per million, for the 3 a.m. sewage between 3 and 12 parts per million. Nearly all of the 3 a.m. sewages have given stable effluents, but the strong morning sewages have quite frequently given putrescible effluents. Unless the sludge is in good condition, and well nitrified, a strong sewage cannot always be purified in 4$\frac{1}{2}$ hours even by increasing the air to 800 cubic feet per 400 gallons. In the normal working of the plant the sludge will usually regain its "activity" if 800 cubic feet of air is applied for several periods after the strong sewage has been added.

At times, however, with a succession of strong sewages, it is necessary to increase the time of aeration in order to obtain good effluents. Ardern and Lockett[15] noted in their first paper that if the aeration was stopped before the sewage was well nitrified, the activity of the sludge would be inhibited. When strong sewages are to be treated a definite cycle of operation probably cannot be established without provision for longer aeration of the sewage or separate aeration of the sludge. In order to keep the sludge in its most active state, complete nitrification of each sewage is necessary. Effluents are usually stable if 50 per cent of the free ammonia is removed, and 2 to 3 parts per million of nitrogen as nitrates is present. A completely nitrified effluent is neither necessary nor economical.

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[15] *Jour. Soc. Chem. Ind.* 33, 623–639.

The greatest efficiency in air consumption will be obtained when enough air is used to make the sewage nonputrescible and to keep the sludge activated. The operation of the plant during six months has suggested the advisability of studying more carefully such other features of the process as the amount of sludge formed, the building up of nitrogen in the sludge and the composition of the effluent gases.